Refinement of the Rapid UT1 Estimation Derived from Tsukuba VLBI Measurements after the 2011 Earthquake

Gerald Engelhardt, Volkmar Thorandt, Dieter Ullrich

Abstract The Tsukuba station in Japan is an essential station in the International VLBI Service for Geodesy and Astrometry (IVS) Intensive series for rapid Universal time (UT1) estimation. The use of this station in rapid UT1 estimation requires a set of best-predetermined station coordinates, but the consequences of the earthquake in Japan in March 2011 were such that the previously known velocity rates of the station Tsukuba were unusable. Since 2012, the VLBI group at BKG has used a method which solves this problem. This procedure was refined with respect to a newly developed extrapolation to get the most probable station positions of Tsukuba for the epochs of the Intensive sessions. The procedure is explained and could be successfully integrated into the technological process of operational analysis of post-quake Intensive sessions with station Tsukuba.

Keywords Rapid UT1 estimation, coordinate series, extrapolation

1 Situation Before and After the 2011 Earthquake

The first successful UT1 Intensive session with the VLBI station Tsukuba in Japan (IVS name Tsukub32) was measured on May 5, 1999. Since then, approximately 823 sessions could be measured until early March 2011. After a big earthquake in the region of the station Tsukuba on March 11, 2011, station displacements up to 67 centimeters occurred. The time series of the station coordinates about 1.5 years before and 4.5 years after the earthquake can be seen in Figures 1, 2, and 3. You can see a big offset in the east compo-

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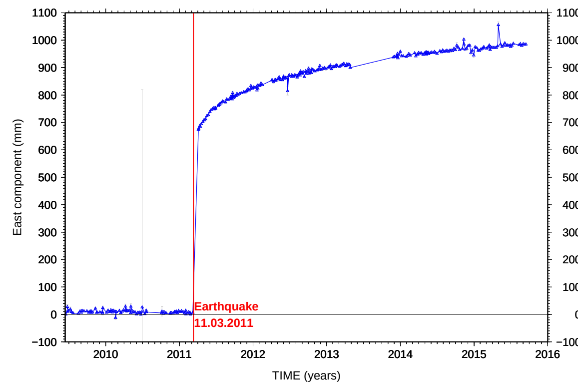

Fig. 1 Station position time series of Tsukub32 (Japan) in east component of VLBI solution bkg00014 in the form of differences to the reference session named R1383 (09JUN15XA).

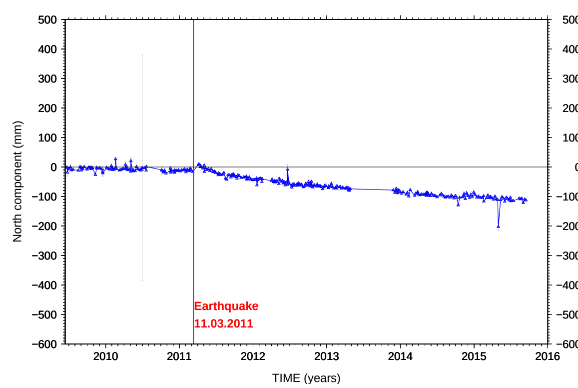

Fig. 2 Station position time series of Tsukub32 (Japan) in north component of VLBI solution bkg00014 in the form of differences to the reference session named R1383 (09JUN15XA).

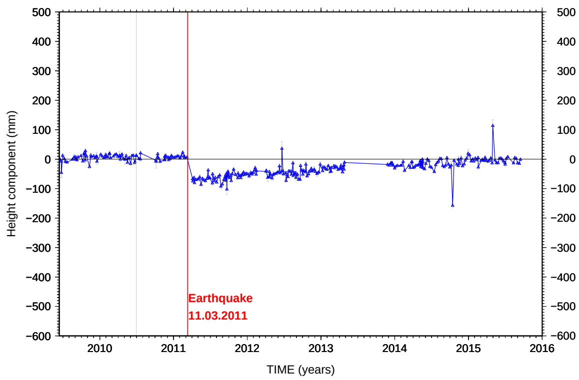

Fig. 3 Station position time series of Tsukub32 (Japan) in the height component of VLBI solution bkg00014 in the form of differences to the reference session named R1383 (09JUN15XA).

nent but also different rates in all components after the earthquake. Therefore, the old velocity rates before the earthquake can no longer be used. A new procedure for getting the best possible coordinates as a prerequisite for a reliable unbiased UT1 estimation is thus necessary.

2 Procedure of Intensive Session Processing (Int2/3)

2.1 Tsukub32 Coordinate Series from BKG Global Solution bkg00014

The BKG global solution bkg00014 [4] for generating terrestrial reference frame (TRF) and celestial reference frame (CRF) realizations, tropospheric parameters, and earth orientation parameter (EOP) series is based on a solution mode with common estimation of all parameter types from 24-hour sessions since 1984. The station coordinates of Tsukub32 are one part of the arc-parameters in sessions with station Tsukub32. The station position time series of Tsukub32 in X, Y, Z coordinate components and their standard deviations are extracted in a first step.

2.2 Tsukub32 Smoothed Pseudo-coordinate Series

The locally determined station coordinates of Tsukub32 and their standard deviations are used for the estimation of a weighted mean between two sequent station positions at the mid-epoch of both single solutions. Thus, a smoothed pseudo-coordinate series of station Tsukub32 can be generated for all coordinate components (X, Y, Z).

2.3 Linear Interpolation

The smoothed pseudo-coordinate series of Tsukub32 is used for linear interpolation between the epochs of two sequent data points to get the most probable station positions for the epochs of Int2/3 sessions. If epochs of Int2/3 sessions exist after the last estimated Tsukub32 position, coordinates of the last 24-hour session of it were used in the old procedure [2].

2.4 Extrapolation

If you need the most probable station positions for the epochs of Int2/3 sessions after the epoch of the last estimated Tsukub32 position from the global solution, then a rate in each coordinate component is used now for the extrapolation. The starting point for this is the estimates of the last seven Tsukub32 positions from the global solution. The process is illustrated by the example of the X coordinate, see Figure 4, but it is also valid for the coordinate components Y and Z.

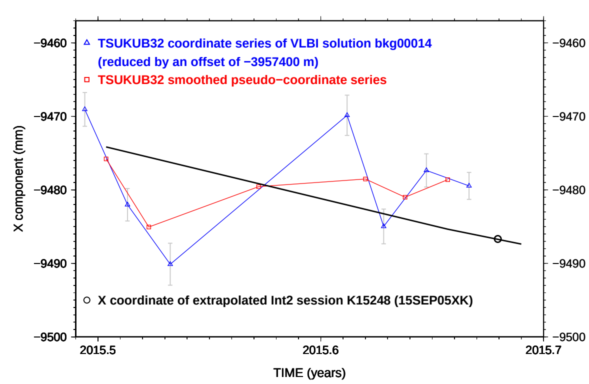

Fig. 4 Example for the extrapolation in coordinate component X for the Int2 session K15248 (15SEP05XK) with actually determined coordinate series and a smoothed pseudo-coordinate series of station Tsukub32 after the March 2011 earthquake.

So:

$$Xg_1, \ldots, Xg_7 \qquad sXg_1, \ldots, sXg_7$$

are given, with

Xg: X coordinate of global solution

and

sXg: standard deviation of Xg.

The process can be divided into four steps:

Step 1: Calculation of smoothed pseudo-coordinates $Xm_1,\ldots,Xm_6$ by weighted mean between two given sequent coordinate values to the respective mean epochs $Em_1,\ldots,Em_6$

Step 2: Calculation of piecewise rates between two sequent smoothed pseudo-coordinate values to their epochs, so

$$\frac{Xm_2 - Xm_1}{Em_2 - Em_1}, \ldots, \frac{Xm_6 - Xm_5}{Em_6 - Em_5}$$

Step 3: Conversion to piecewise rates per year and estimation of the average rate $vX(mean)$

Step 4: Based on $vX(mean)$ it is possible to compute the station coordinate for the epoch of the respective Int2/3 session starting from the middle of the period $Em(mean)$ derived from $Em_1,\ldots,Em_6$ and the average coordinate $Xm(mean)$ derived from $Xm_1,\ldots,Xm_6$.

An example of the extrapolation of the X coordinate for the Int2 session K15248 (15SEP05XK) is shown in Figure 4.

2.5 UT1 Estimation

After determination of the most probable station positions of Tsukub32 for the epochs of Int2/3 sessions, regular analysis can be executed. The estimated parameter types are the difference between UT1 and international atomic time (TAI), station clock, and zenith troposphere together with fixed station coordinates in VLBI TRF, realization 2008a [1] and radio source positions from *International Celestial Reference Frame, second realization (ICRF2)* [3]. The reliability of the determination of UT1-TAI depends significantly on the accuracy of the fixed station coordinates. Thus, a coordinate change of one centimeter in the eastern component of Tsukub32 causes a UT1-TAI change of about 15.5 microseconds in the example session K15248.

3 Integration in Technological Process

The above described single steps for handling the Int2/3 sessions with station Tsukub32 were combined into a semi-automatic process. The newly determined a priori station coordinates for each Tsukub32 Intensive session are used as input for the session by session Tsukub32 Intensive cycle run. Finally, an IVS formatted EOP list is created and mixed with the non-Tsukub32 IVS EOP list. These algorithms were included in the BKG post-interactive part of establishing the IVS EOP solutions.

4 Conclusions

On the basis of an interpolation and extrapolation procedure of the station position time series of Tsukub32 derived from a global solution with all 24-hour sessions, the most probable station positions of Tsukub32 for the epochs of the Intensive sessions can be estimated.

A great advantage of this method is that the same VLBI antenna at the station Tsukub32 is used for the 24-hour sessions and Int2/3 sessions. The new extrapolation method prevents the sole use of a specific weak Tsukub32 position from the global solution, resulting in a higher reliability of Tsukub32 coordinate determination at the epochs of Int2/3 sessions.

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